

Historical Data on Characteristics of Radio Systems Used for United States Deep-Space Communications

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Historical data on selected communication parameters are presented in tables and charts for 14 deep-space missions. Some observations are made about trends in communication capability.

I. Introduction

The DSN is engaged in examining past trends and future requirements to assure the timely development and implementation of systems to support deep-space radio communications. In connection with this effort, historical data on selected characteristics of past and present spacecraft communication systems has been gathered and is presented in this article.

II. Selected System Characteristics

The characteristics selected as indications of communication capability are:

- (1) Maximum and minimum telemetry rate.
- (2) Command rate.
- (3) Command word length.
- (4) Data storage capacity.
- (5) Spacecraft antenna size.
- (6) Spacecraft transmitter power.

Values for these parameters are tabulated and plotted for 14 missions. The 17 spacecraft included in these missions are

listed in Table 1 along with their launch dates. Subsequent Tables 2 through 4 list the parameter values associated with each mission, not each spacecraft.

Parameter values are plotted in Figs. 1 through 9 as a function of time to make trends visible. In some cases, the arithmetic values listed in the tables have been converted to logarithmic (dB) values in the corresponding figures. For example, the 16.2-k bits/s maximum telemetry rate for Mariner-Mars 69 has been plotted as 42 dB (bits/s). This plotting method was used because it is often convenient to think of relationships between communication parameters in terms of logarithmic values expressed in the form of decibels.

III. Performance Ratios and Figure of Merit

In an attempt to shed additional light on the changing capability of deep-space communications, ratios of some parameters have been taken. These ratios are expressed logarithmically and are:

$$\beta_1 = 10 \log \frac{\text{maximum telemetry rate}}{\text{minimum telemetry rate}}$$

$$\beta_2 = 10 \log \frac{\text{maximum telemetry rate}}{\text{command rate}}$$

The reader is invited to consider the meaning and implications of these ratios shown in Figs. 10 and 11. For example, the decrease in ratio of telemetry rate to command rate since 1973 seems to illustrate the increasingly complex control that is demanded by spacecraft designed to be largely autonomous in executing desired sequences of events during critical periods such as planetary encounter.

A telemetry figure of merit has also been derived as shown in Fig. 12. It is a logarithmic expression that includes the maximum telemetry rate and the square of the communication distance at planet encounter. The telemetry rate is related to the sum of all the spacecraft and ground performance parameters, including antenna size, transmitter power, receiver noise temperature, and coding gain. The communication distance is squared to account for the inverse square law of free-space propagation.

The unchanged value of the telemetry figure of merit since 1977 is indicative of economic constraints on the development of increased communication capability.

For missions beyond Jupiter, the current figure of merit dictates that the data rate must be correspondingly reduced below 115 kbits/s. No change to ground equipment is needed to accommodate these lower rates. In contrast, the current

figure of merit yields a data rate capability of 1 Mbit/s for the proposed VOIR mission to Venus. In this case, changes are required to ground equipment if the radio communication capability is to be fully utilized. This is because existing telemetry demodulation and detection equipment will not handle a rate as high as 1 Mbit/s. (The figure of merit presented here does not include the enhancement of ground antenna arraying).

IV. Further Work

An important element of deep-space communication is the navigation and scientific data obtained from radio metric measurements. The accuracy of these has improved with time, and it would be interesting to trace this development. There are, however, numerous parameters involved and it is not yet clear that the needed historical data is available, or how a meaningful presentation could be accomplished. It is expected that further study will be undertaken.

V. Information Sources

Data collected for this article was found in an extensive set of project reports, handbooks, requirements documents, support plans, and NASA histories. The authors may be contacted for information about these sources.

Table 1. Mission launch date

Mission	Launch date
Mariner-Mars 64 (Mariner 4)	November 28, 1964
Pioneer 6	December 5, 1965
Pioneer 7	August 17, 1966
Mariner-Venus 67 (Mariner 5)	June 14, 1967
Pioneer 8	December 13, 1967
Pioneer 9	November 8, 1968
Mariner-Mars 69 (Mariner 6)	February 25, 1969
Mariner-Mars 69 (Mariner 7)	March 27, 1969
Mariner-Mars 71 (Mariner 9)	May 30, 1971
Pioneer 10	March 3, 1972
Pioneer 11	April 6, 1973
Mariner-Venus-Mercury 73 (Mariner 10)	November 3, 1973
Viking 75 (Viking 1)	August 20, 1975
Viking 75 (Viking 2)	September 9, 1975
Voyager 1	August 20, 1977
Voyager 2	September 5, 1977
Galileo	February 1984

Table 2. Telemetry rate

Mission	Minimum telemetry rate S-band, bits/s	Maximum telemetry rate S-band, bits/s	Minimum telemetry rate X-band, bits/s	Maximum telemetry rate X-band, bits/s
Mariner-Mars 64	8-1/3	33-1/3	(see footnote a)	
Pioneer 6	8	512		
Pioneer 7	8	512		
Mariner-Venus 67	8-1/3	33-1/3		
Pioneer 8	8	512		
Pioneer 9	8	512		
Mariner-Mars 69	8-1/3	16.2 K		
Mariner-Mars 71	8-1/3	16.2 K		
Pioneer 10	16	2048		
Pioneer 11	16	2048		
Mariner-Venus-Mercury 73	8-1/3	117.6 K		
Viking 75	8-1/3	16.2 K		
Voyager	10	115.2 K	10	115.2 K
Galileo	40	115.2 K	40	115.2 K

^aBlank entries indicate that spacecraft did not have X-band telemetry capability.

Table 3. Spacecraft characteristics

Mission	Diameter or size, m	Antenna gain S-band, dBi	Antenna gain X-band, dBi	Spacecraft transmitter power S-band, W
Mariner-Mars 64	Elliptic reflector 1.17×0.54	23.3		20
Pioneer 6	Colinear broadside array	11.2		8
Pioneer 7	Colinear broadside array	11.2		8
Mariner-Venus 67	1	25.8		20
Pioneer 8	Colinear broadside array	11.2		8
Pioneer 9	Colinear broadside array	11.2		8
Mariner-Mars 69	1	25.8		20
Mariner-Mars 71	1	25.8		20
Pioneer 10	2.75	32.6		8
Pioneer 11	2.75	32.6		8
Mariner-Venus-Mercury 73	1.4	28.0	38.8	20 ^a
Viking 75	1.5	28.1	39.5	20 ^a
Voyager	3.7	35.3	48.2	20 (S and X)
Galileo	4.8	38.5	50.3	20 (S and X)

^aMariner-Venus-Mercury 73 and Viking 75 carried 250-mW experimental X-band transmitters.

Table 4. Command rate, bits per command word, and spacecraft data storage capacity

Mission	Command rate, bits/s	No. of bits per command word	Data storage capability, bits
Mariner-Mars 64	1	26	5.24×10^6
Pioneer 6	1	23	15232
Pioneer 7	1	23	15232
Mariner-Venus 67	1	26	10^6
Pioneer 8	1	23	15232
Pioneer 9	1	23	15232
Mariner-Mars 69	1	26	1.8×10^8
Mariner-Mars 71	1	26	1.8×10^8
Pioneer 10	1	22	49152
Pioneer 11	1	22	49152
Mariner-Venus-Mercury 73	1	26	1.8×10^8
Viking	4	67	11.2×10^8
Voyager	16	87	538×10^6
Galileo	32	48	269×10^6

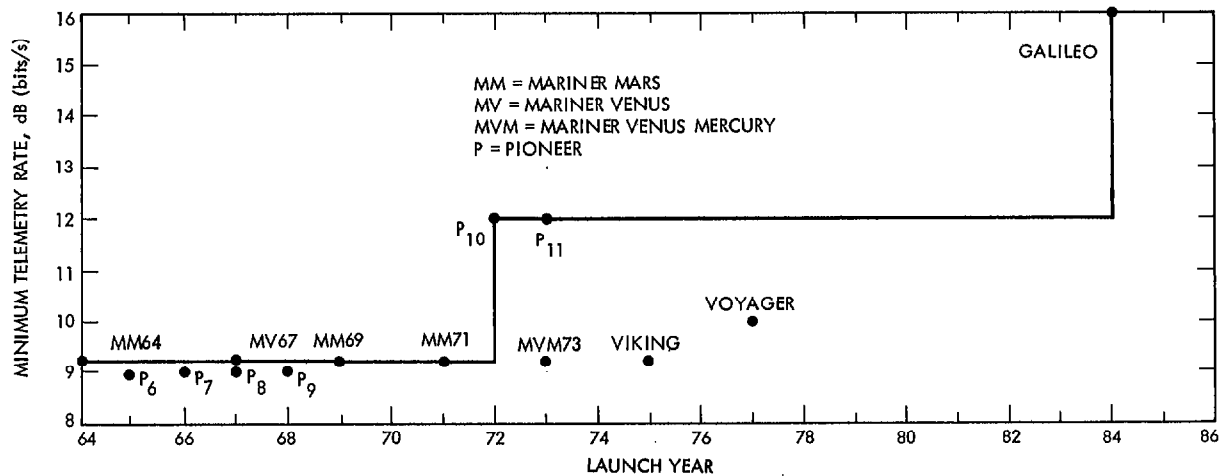


Fig. 1. Minimum telemetry rate vs launch year

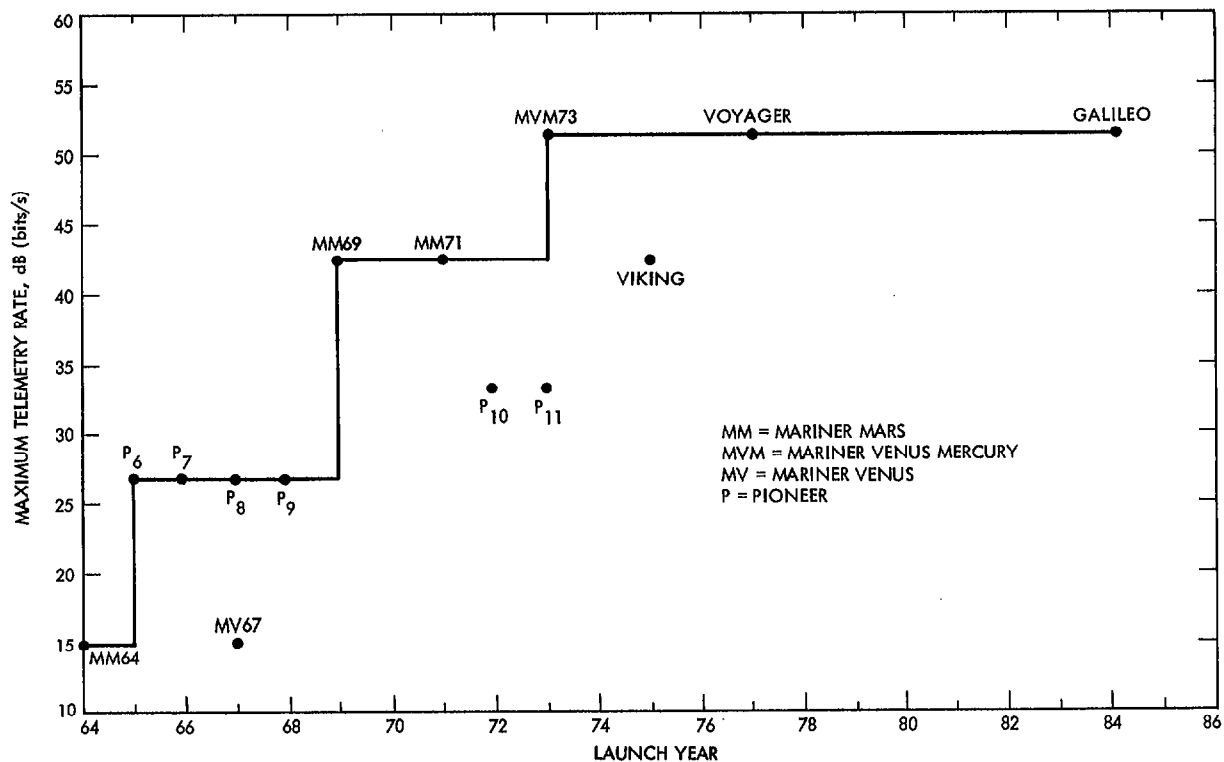
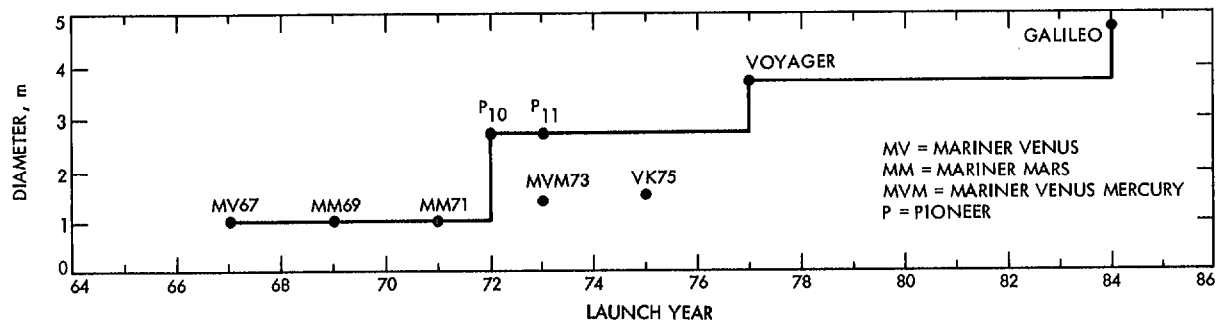


Fig. 2. Maximum telemetry rate vs launch year



MM64 HAD 1.17 X 0.54 ELLIPTIC REFLECTOR
P6-9 HAD COLINEAR BROADSIDE ARRAY

Fig. 3. Spacecraft antenna diameter vs launch year

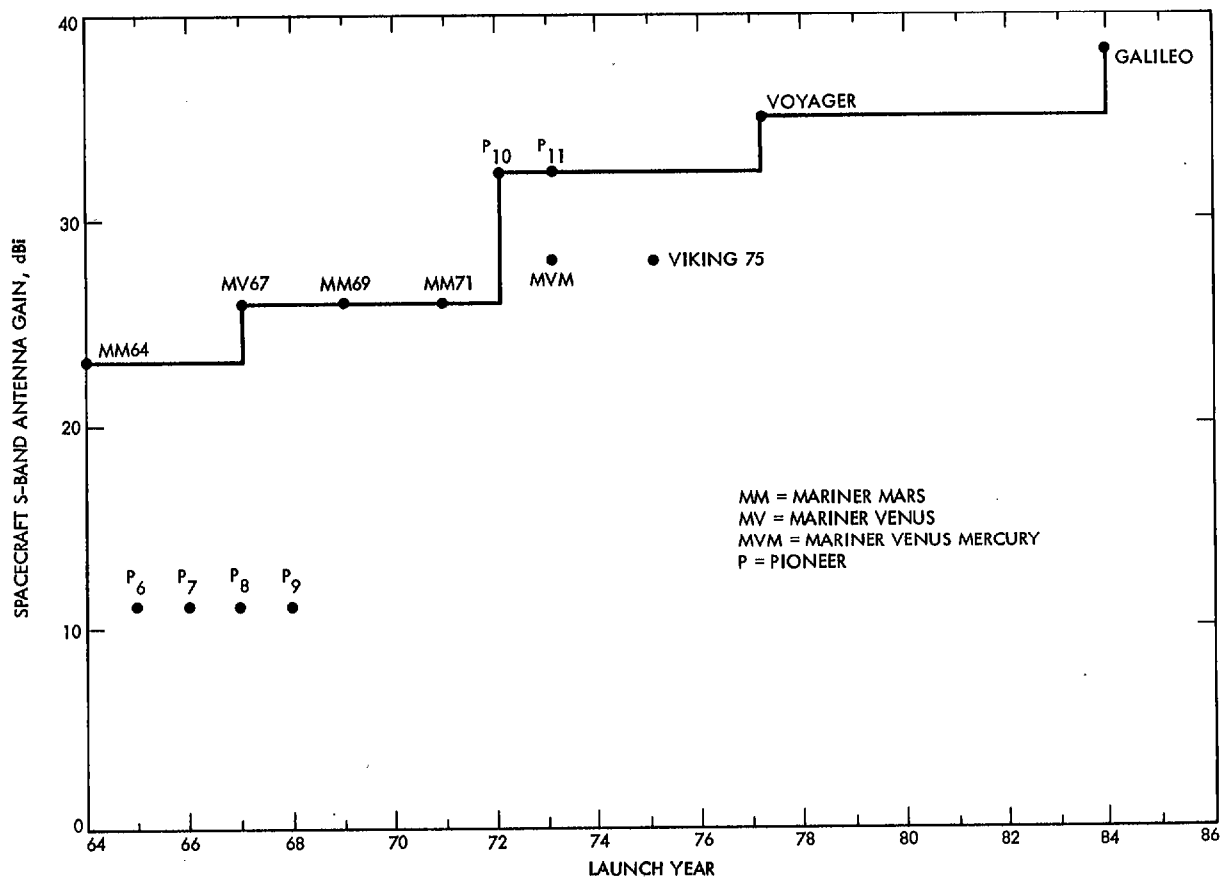


Fig. 4. Spacecraft S-band antenna gain vs launch year

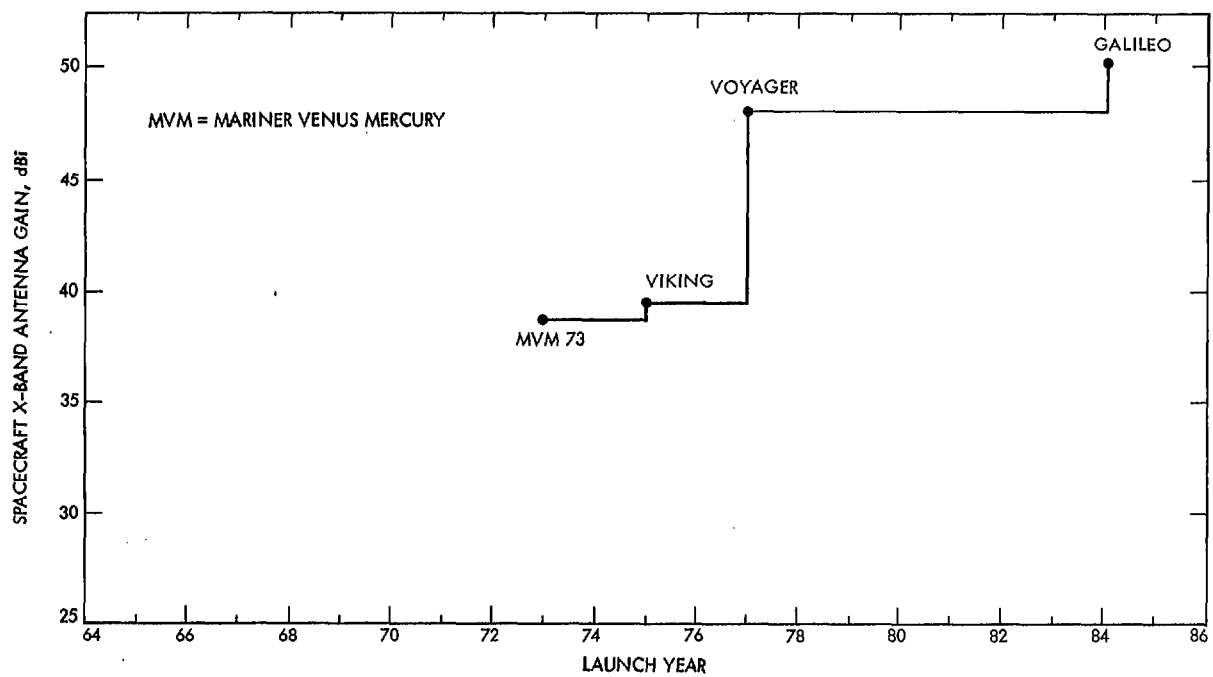


Fig. 5. Spacecraft X-band antenna gain vs launch year

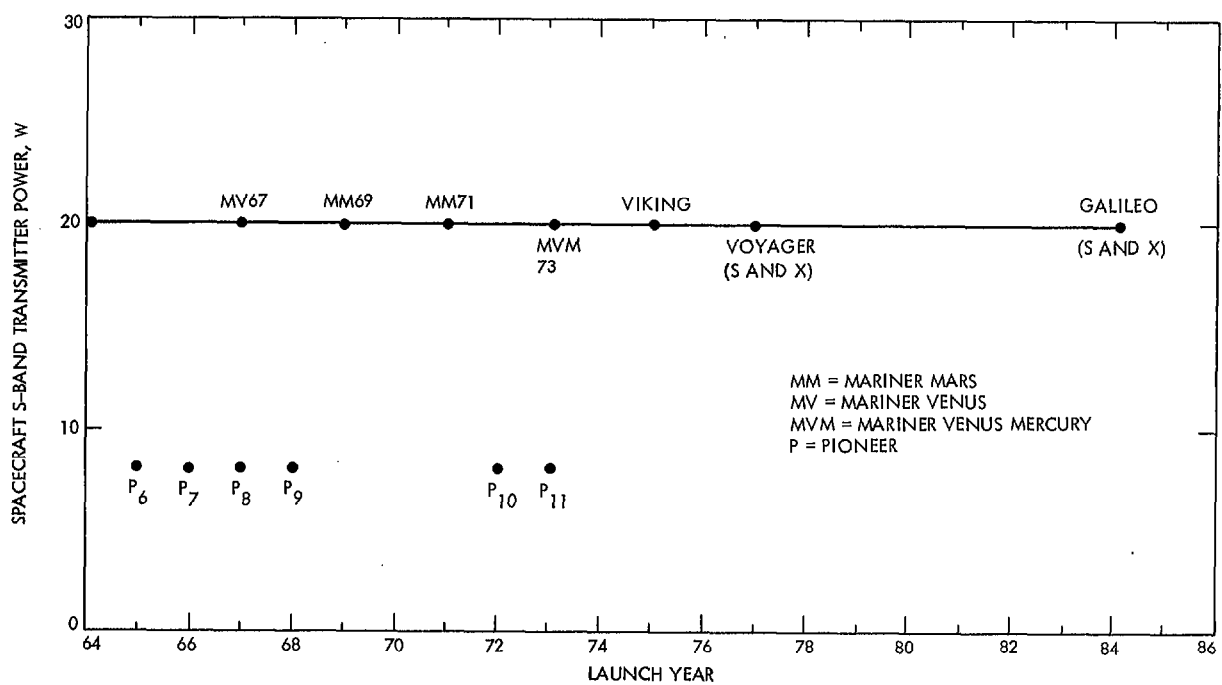


Fig. 6. Spacecraft transmitter power vs launch year

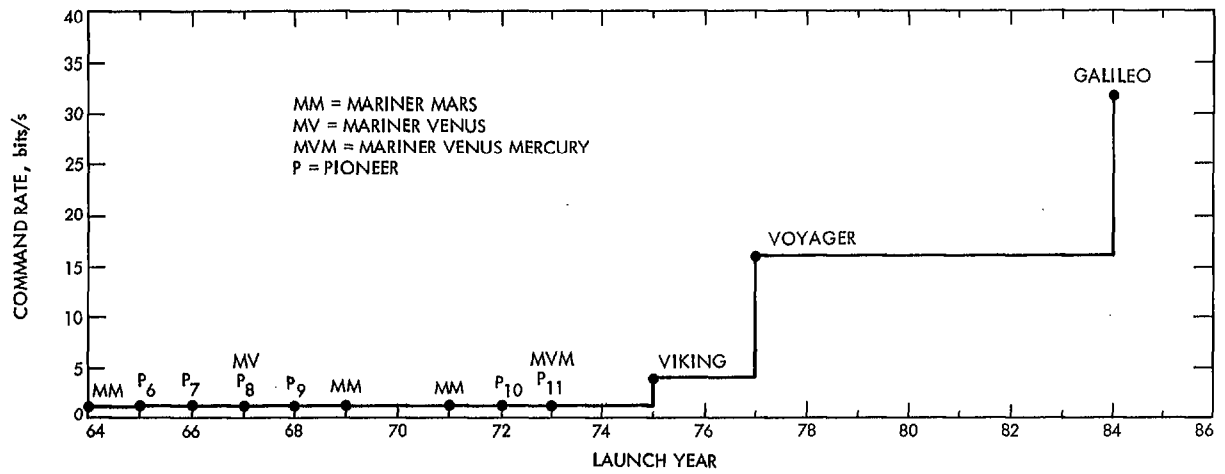


Fig. 7. Command rate vs launch year

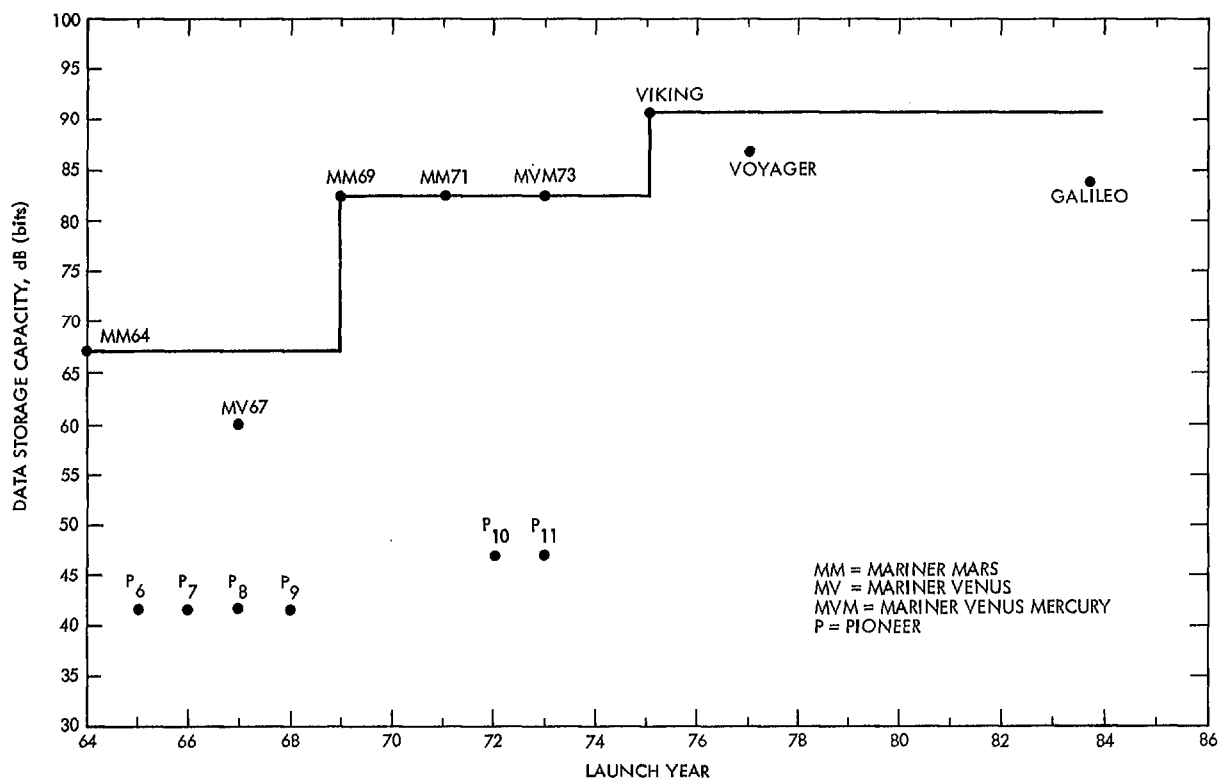


Fig. 8. Spacecraft data storage capacity vs launch year

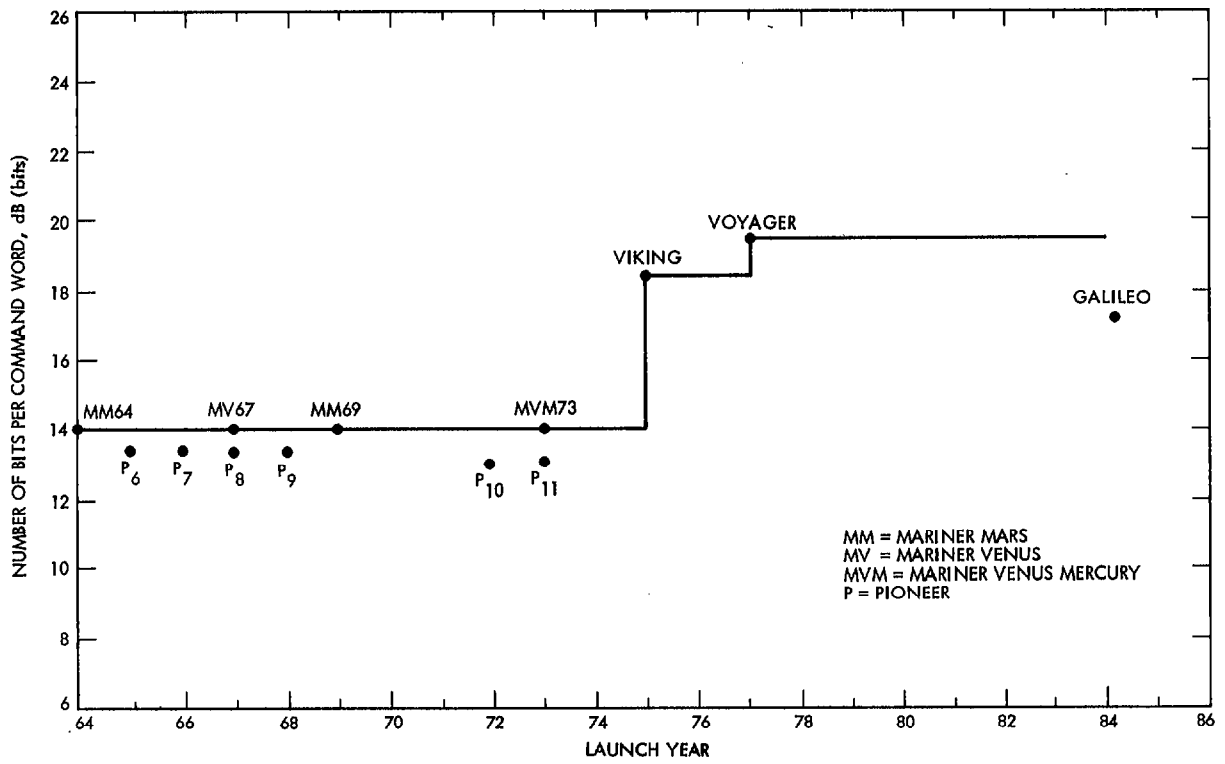


Fig. 9. Number of bits per command word vs launch year

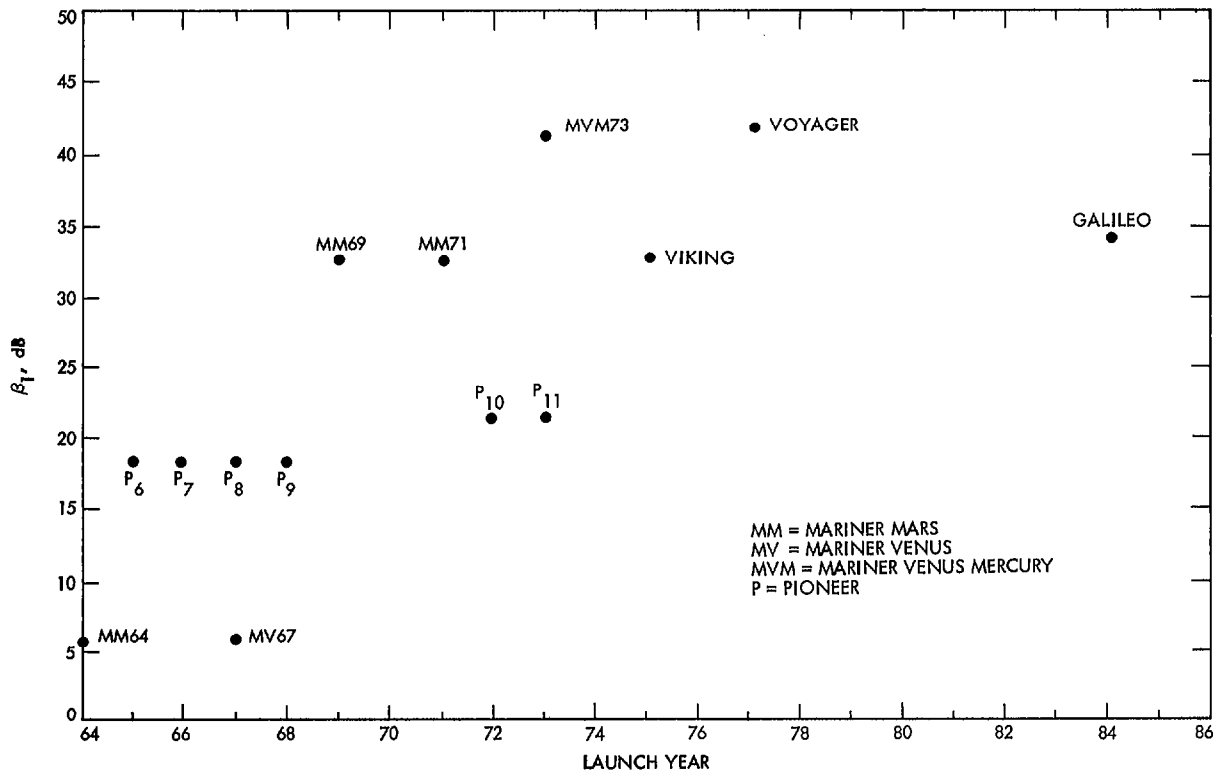


Fig. 10. Ratio β_1 vs launch year

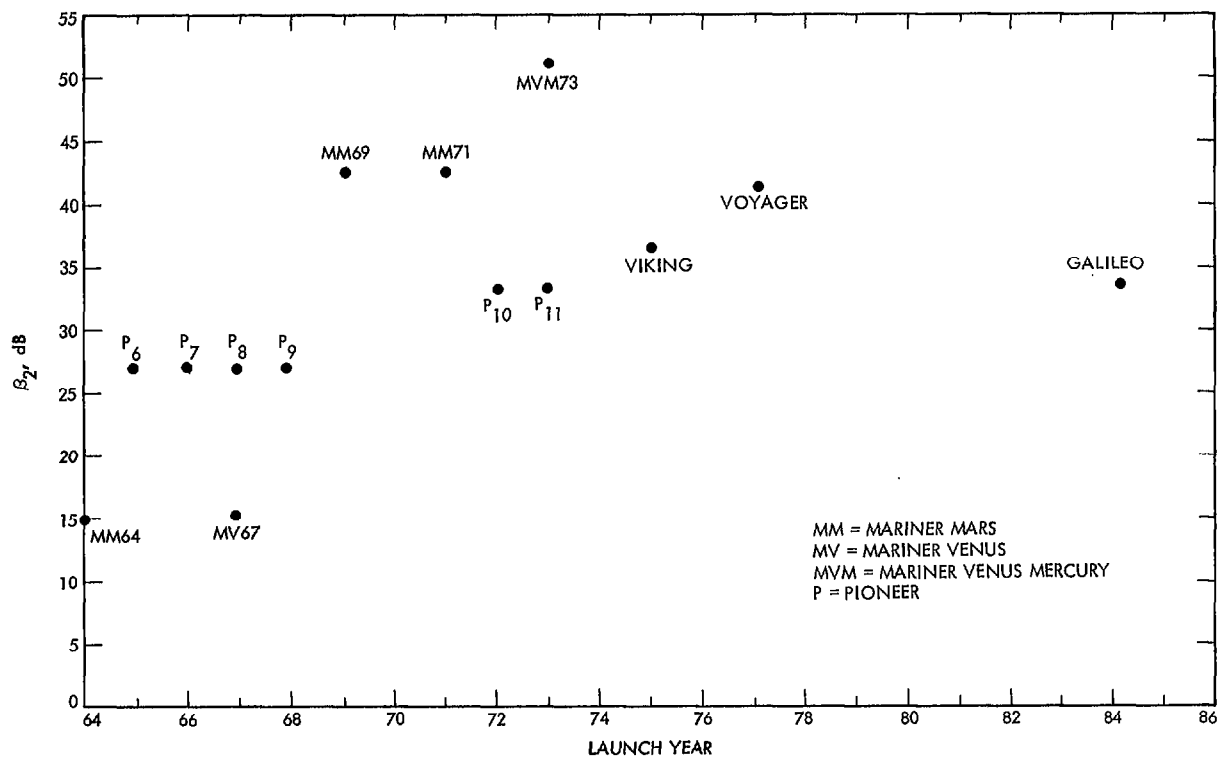


Fig. 11. Ratio β_2 vs launch year

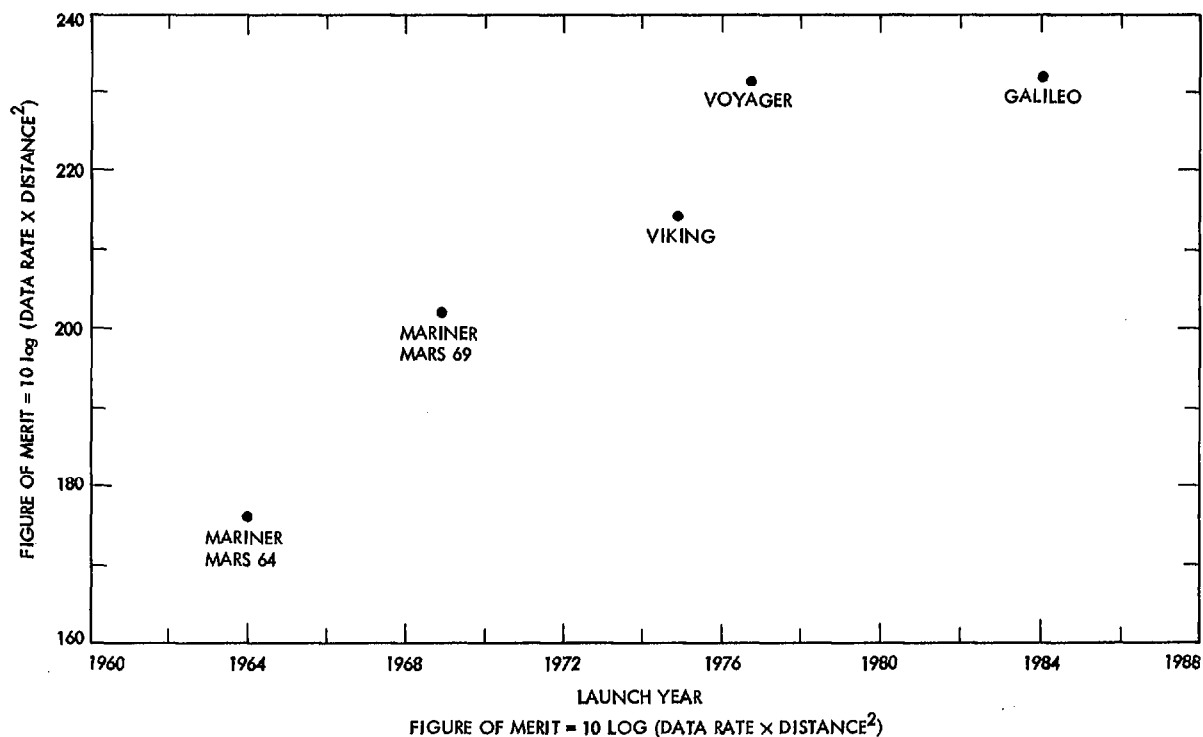


Fig. 12. Telemetering figure of merit vs launch year